SToRM SAR (Instrument Incubator)

Satellite Tomography of Rain and Motion via Synthetic Aperture Radar

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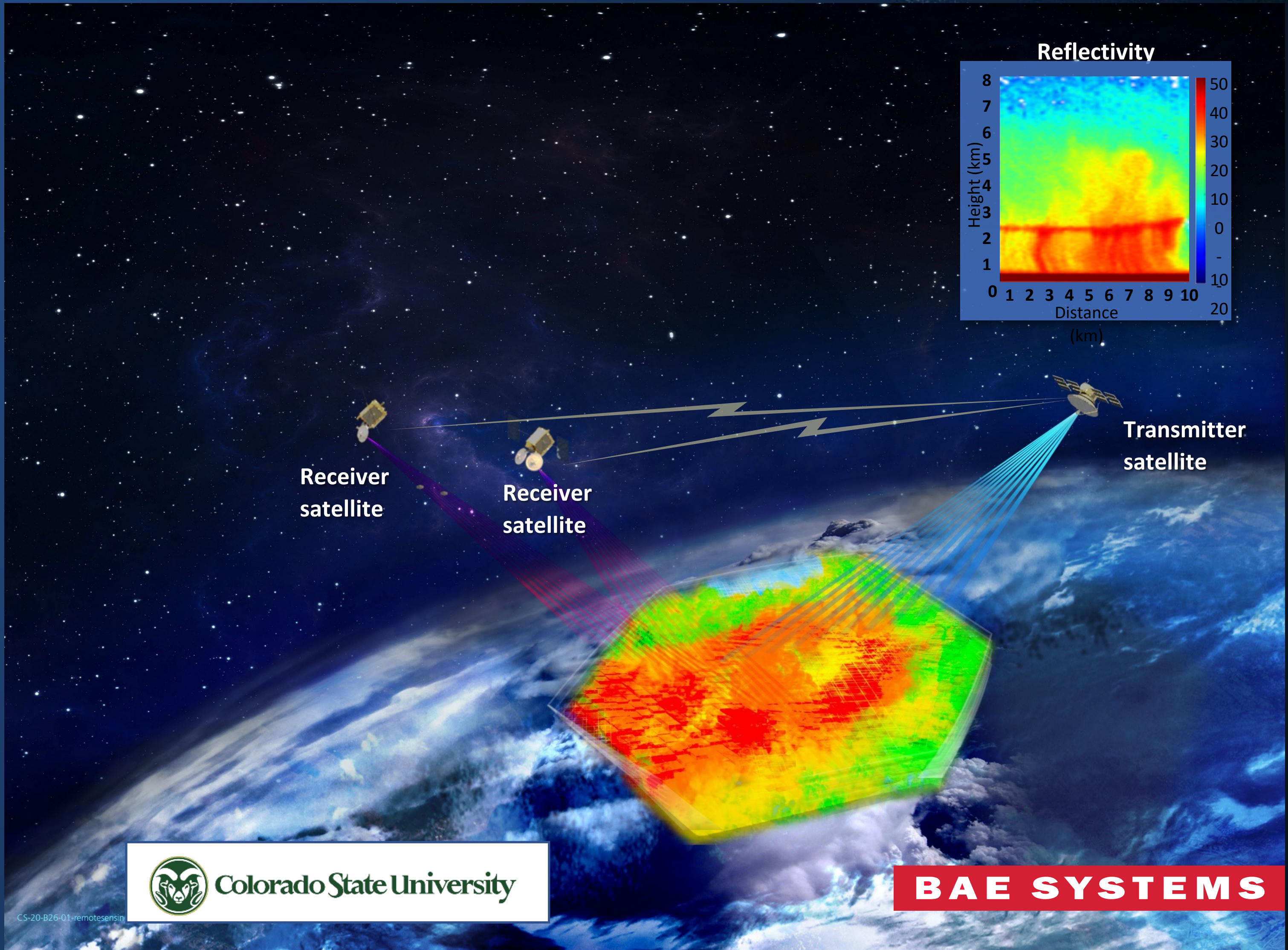
Concept Summary

- Precipitation Observations from space at ~ 1 km horizontal resolution are needed to characterize severe storm processes for weather research
- Providing these observations via up-scaled real-aperture methods would be very costly
- SToRM employs a distributed architecture of microsatellites to implement a networked weather radar



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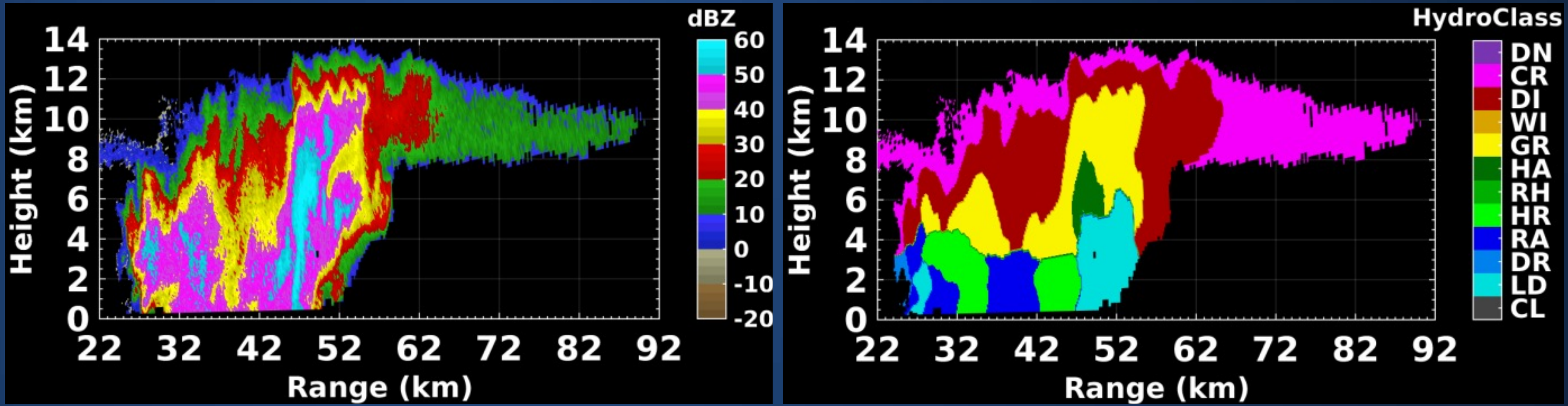
Ground-Based Radar Observations Illustrate that ~ 1 km Horizontal Resolution Needed to Characterize Severe Storms



Radar Reflectivity Cross Section and Hydrometeor (classified) Cross-Section for a Precipitation Event Observed at 23:43UTC, May 29, 2013 by NPOL during the IFLOOD Field Campaign (HydroClass: CL: Clear Air, LD: large drops, DR: drizzle, RA: rain, HR: heavy rain, RH: rain plus hail, HA: hail, GR: graupel, WI: wet ice, DI: dry ice, CR: crystals)

<u>ESAS 2017 References:</u>

Question W2 :improving weather forecasting

- Vertical Distribution of Precipitation Particles
- Liquid and Ice Water Paths

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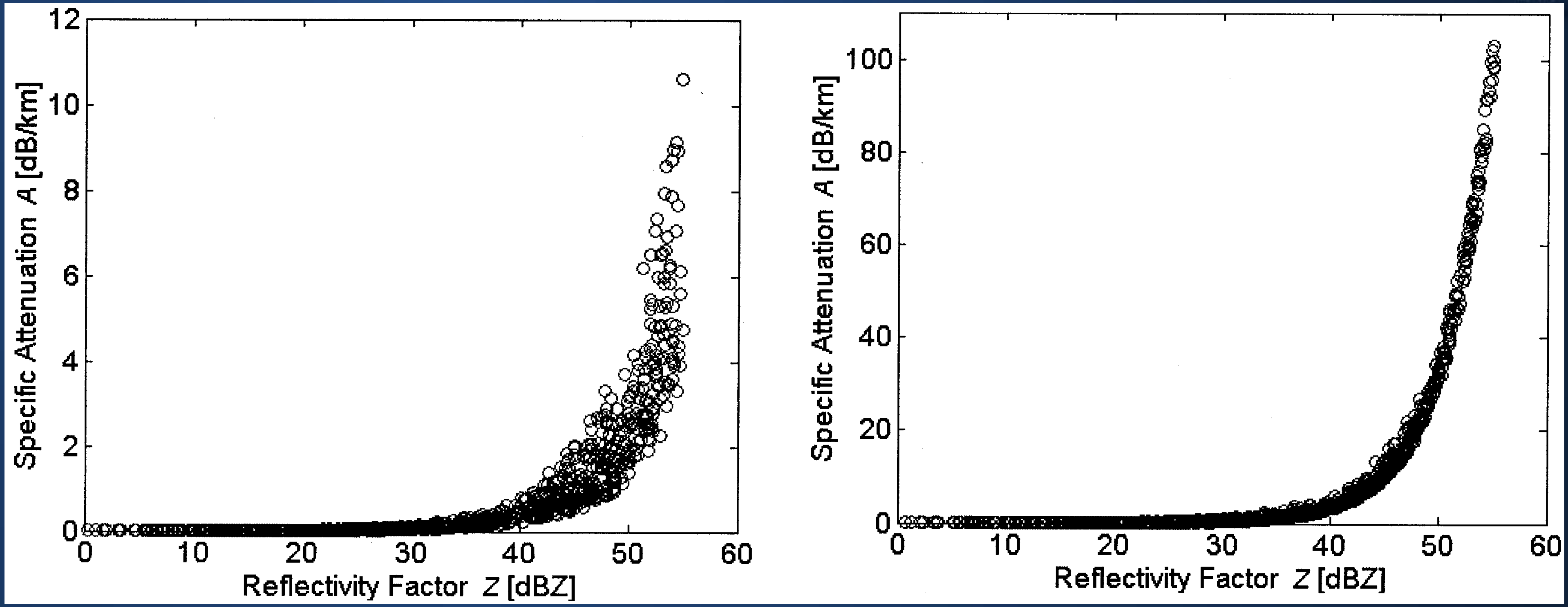
Specific Attenuation at Ka and Higher Frequencies Limits Vertical Profiling of Intense Convective Storms



Global Mapping of Attenuation at Ku- and Ka-Band

V. Chandrasekar, Hiroki Fukatsu, and K. Mubarak

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 41, NO. 10, OCTOBER 2003

While Real-Aperture Diffraction-limited Footprints (and Antennas) are Smaller at Ka, Path Attenuation is Much Higher

Geometry for Simulation of SAR for Precipitation Observation from Space-for This Example

GPM Ku-DPR Parameters used

Frequency: 13.9 GHz (Ku band)

Height: 400 km

Speed: 7670 m/s

HPBW: 0.71 degrees

Antenna size: 1.7404 m

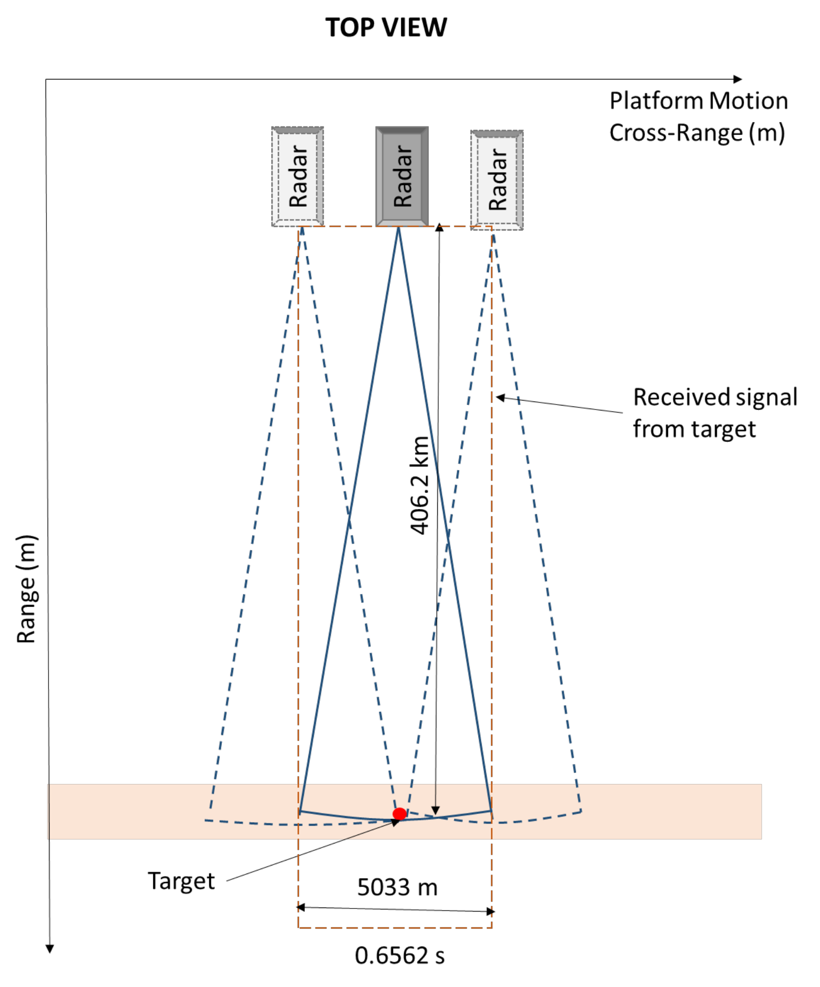
PRF: 18 KHz

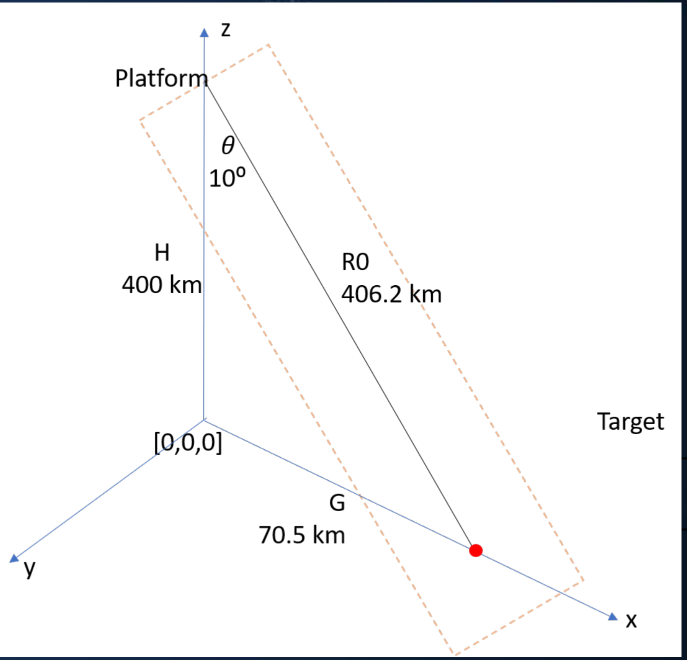
Duration of data capture: 2.63 s

Pulse duration: 1 us

Sampling frequency: 200 MHz

Footprint of target: 5.033 km



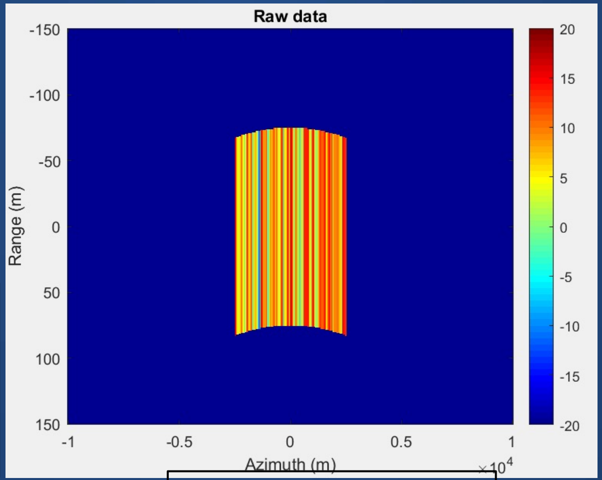


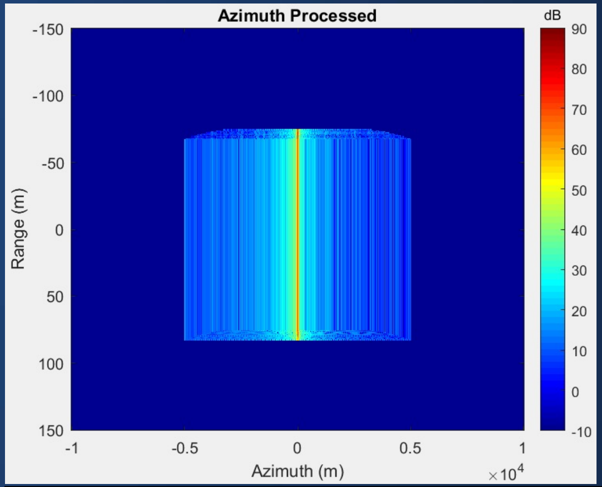
R0: Slant range to target at side looking direction
Theta: Incidence angle
H: Height from the ground
G: Target distance on ground

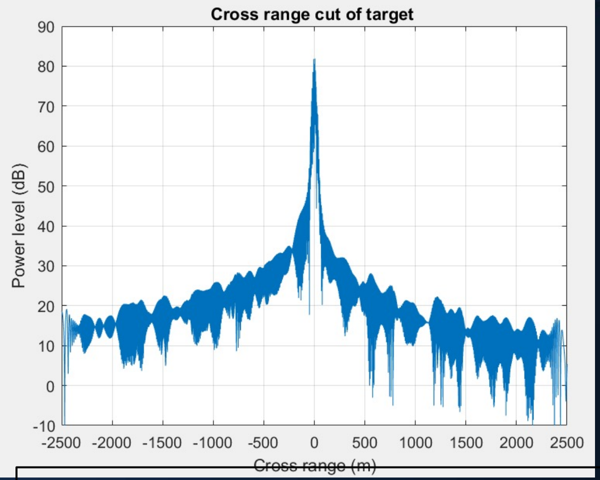
Simulations of Along-Track Resolution of Precipitation Target Indicates Potential for < 1 km Resolution

Doppler Spread Based on Drop Size Distribution: 0.25 m/s

Upper Panels: Precipitation Target- Statistical model





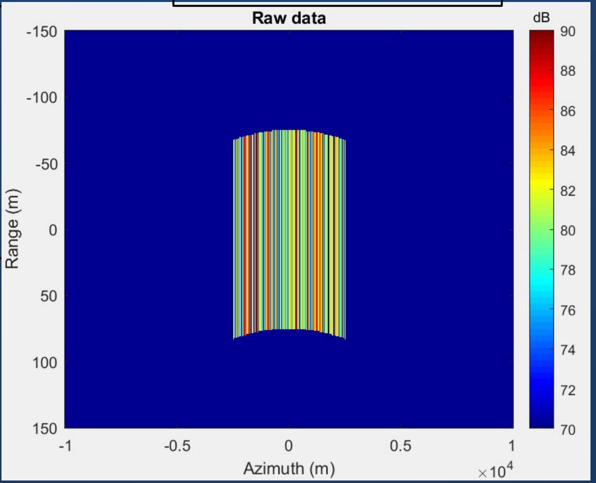


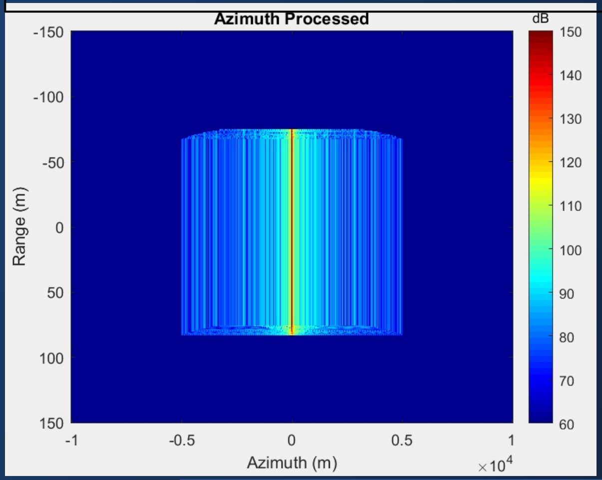
Range/Doppler

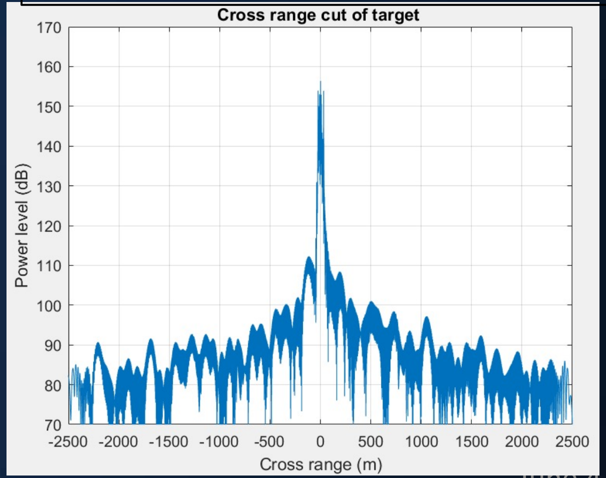
After Range Compression

Results for “Point”Target” region

Lower Panels: Precipitation Target Explicit drop by drop model





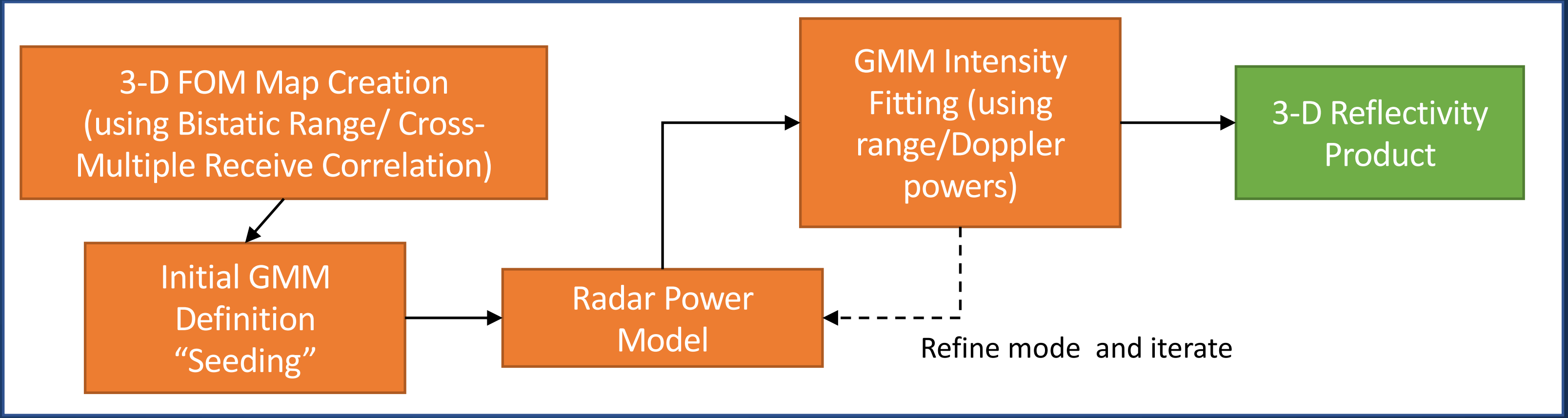


Expected resolution:

$$\delta'_a = \frac{V_a}{f'_B} = \frac{\sqrt{2}\pi R\sigma_v}{V_a}$$

58.8 m for this example

Framework for Retrieval of 3D Reflectivity from Multiple Bi-Static Observations at Different Angles



- Power measured for each Range/Doppler bin (and each SV/dwell) is a sum of the precipitation return, ground clutter, and thermal noise
  - Precipitation return is sum over mixture model components
  - Clutter return binned by bistatic bisector angle for simple model
- Measurements over multiple dwells with different look angles provides “rotation” necessary for tomographic inversion process

$$P_{total}\left(i_{Doppler}\,, j_{Range}\right) = P_{sky}(i,j) + P_{clutter}(i,j) + P_{noise}(i,j)$$

$$P_{total}(i,j) = \sum_{cells} Z_{\max(cell)} A(cell,i,j) + \sum_{\beta\ bins} \sigma^0_{bin} B(bin,i,j) + P_{noise}(i,j$$

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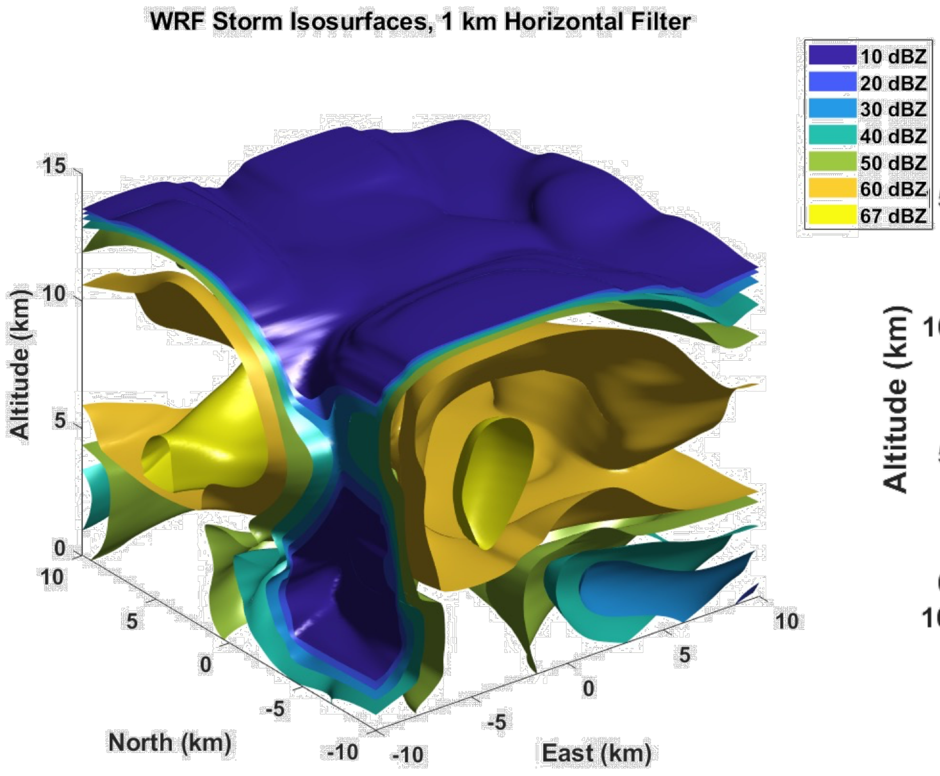
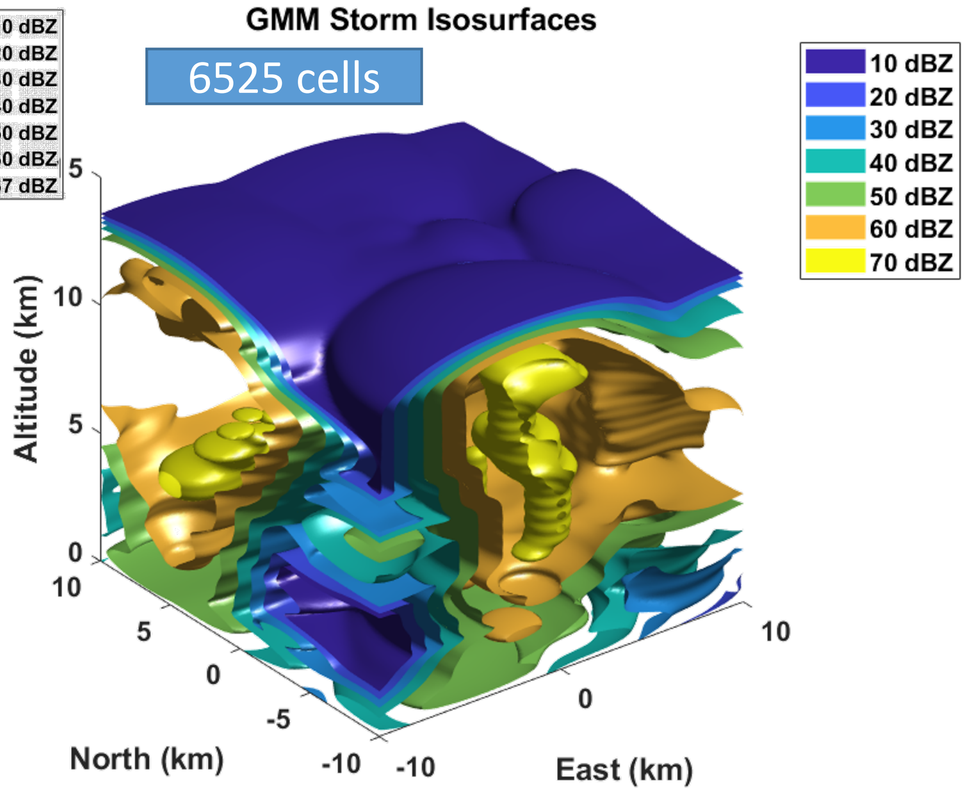
Representing a Precipitation Field via Gaussian Mixture Model- Minimizes the Number of Degrees of Freedom Needed to Model Field

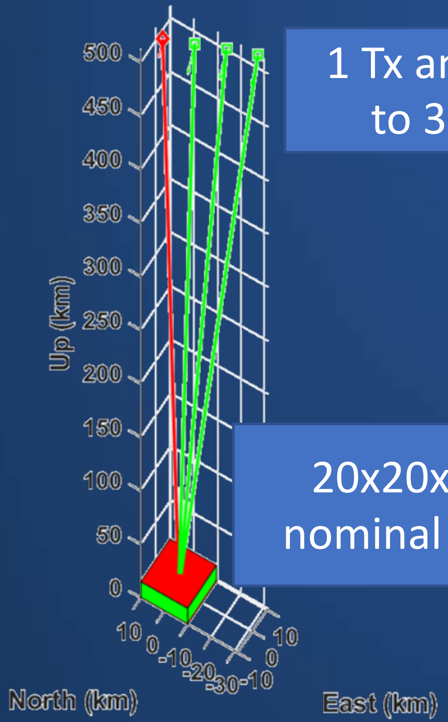
WRF Model output has adjacent (400 m) points with 80 dB change; applied 1 km filter

Direct nonlinear least squares fit; In center 10x10 region, RMS is 4.7 dB, 90% within 5.5 dBZ





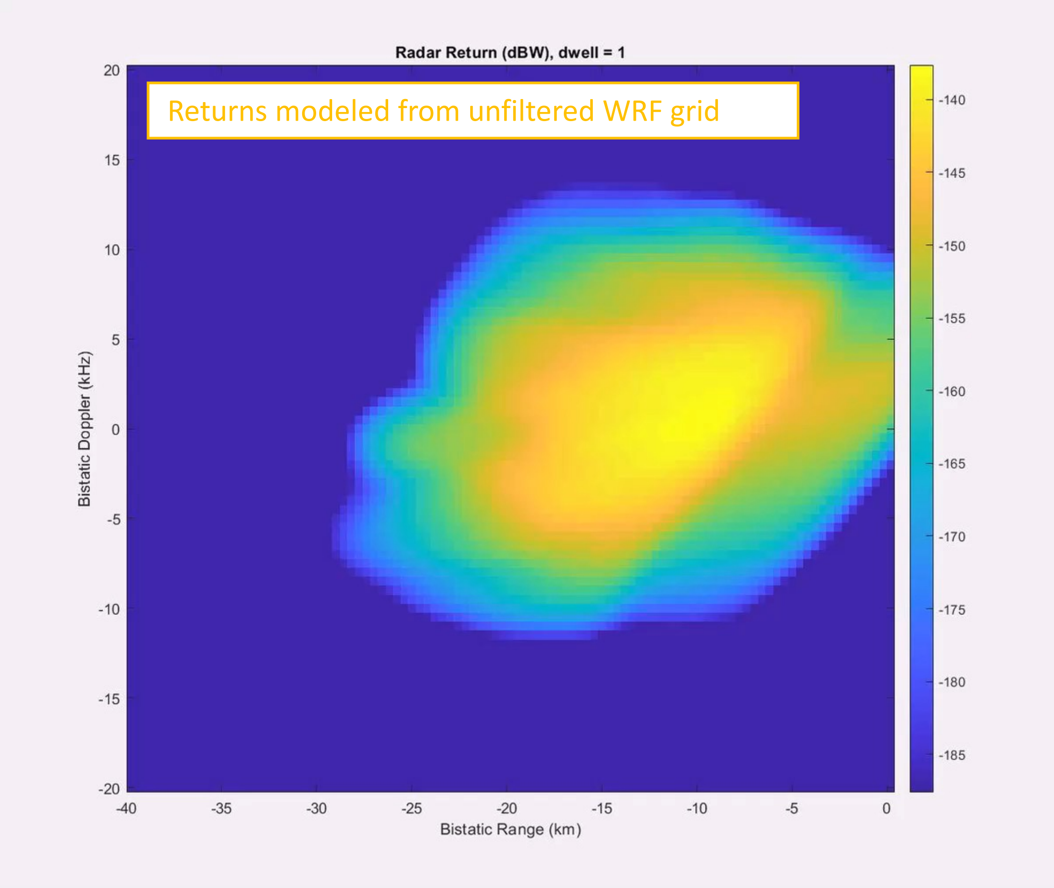
Radar Power Model simulates the SToRM SAR observation to develop data for tomography inversion



1 Tx and up to 3 Rx

20x20x15 km nominal volume

15 “dwells” during an overpass; note how changes over the looks, this is what we use to infer 3-D structure



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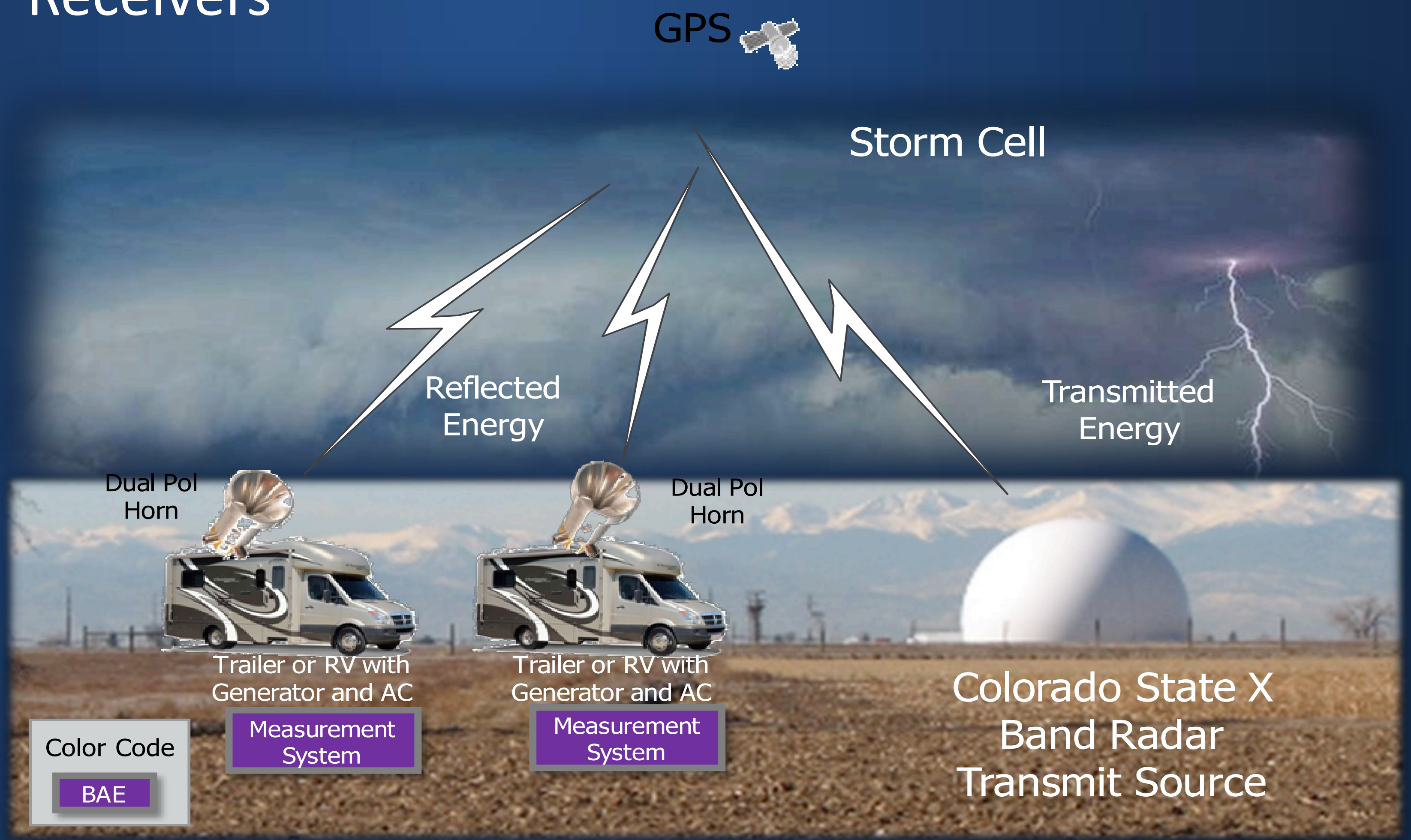
Ground-Based Bi-Static Field Tests Planned for 2021/22 using the NSF CHILL Precipitation Radar and Separated Receivers



Key Field Test Purpose

- Demonstrate Multi-Static Interferometry Method on Real Storms
- Compare Results with Real-Aperture Precipitation Radar at X-Band

Summary

- Precipitation Observations from space at ~ 1 km horizontal resolution are needed to characterize severe storm processes for weather research
- Current PR pathways to provides this vertical profile observation face significant technology barriers
  - Providing very large apertures
  - Overcoming very high attenuation at Ka and higher RF frequencies
- SToRM employs a distributed architecture of microsatellites to implement a networked weather radar
  - Method Elements Under Development (currently TRL-2)
  - RF Hardware Technology Sufficiently Mature
- Detailed Precipitation Simulations showing < 1 km along-track resolution under certain conditions
  - Doppler dispersion from drop size distribution or wind causes some spreading, < 1 km
- Ground-based multi-static PR field tests at NSF CHILL planned for Summer/Fall 2021

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